THE ECONOMY RESULTING FROM THE USE OF VARIABLE SPEED INDUCTION MOTORS FOR DRIVING CENTRIFUGAL PUMPS[1]

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The centrifugal pump is inherently a variable speed machine. Figure 1 shows the relations between quantity, head and speed in the case of a typical centrifugal pump. An examination of the figure will show that when any two of the three variables are selected the third is determined. For example, if the speed and quantity are chosen the head is determined. With the usual arrangement of an induction motor direct-connected to a centrifugal pump the speed is fixed. The speed of an induction motor is not quite constant but decreases with increasing loads affecting the relation of the head and quantity delivered by the pump somewhat as indicated by the dotted line in figure 1. The variation in speed is so small, however, that the induction motor is usually considered to be a constant speed machine.

There are four general conditions under which pumps operate: (1) constant discharge against a constant head, (2) constant discharge against a variable head, (3) variable discharge against a constant head, and, (4) variable discharge against a variable head. The first condition is the ideal one for centrifugal pumps driven by constant speed motors. Pumps delivering water to filter plants or to surface condensers often fall into the second class. The third condition is probably a rare one. In the fourth class would be included pumps used in waterworks plants for delivering water into distribution systems, because in this case variations of the water level in reservoirs and elevated tanks cause the head to vary while variations in demand cause the quantity delivered by the pump to vary. In the last three cases it is customary to select motor-driven centrifugal pumps operating at constant speed which will operate

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satisfactorily under the most adverse conditions, and to control the head and discharge by valves at all other times.

The variable speed induction motor has a wound rotor with its terminals connected to slip rings so that resistances may be introduced into the rotor circuit to change the speed. The action is

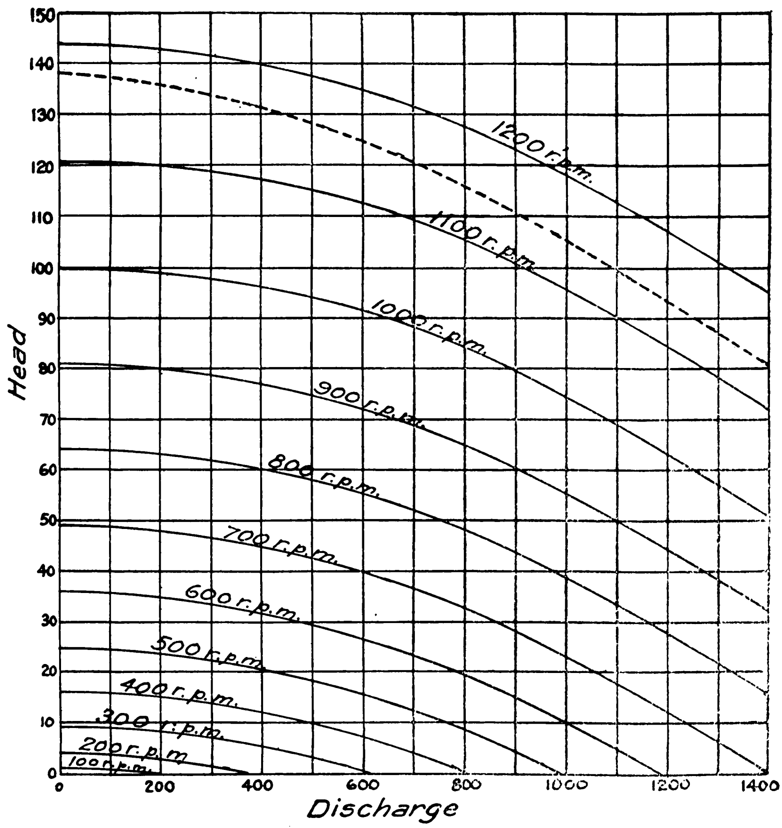

FIG. 1. RELATIONS OF SPEED, DISCHARGE AND HEAD WITH A TYPICAL CENTRIFUGAL PUMP

somewhat analogous to slipping a clutch to secure lower speeds, and is of course wasteful. In the *Standard Handbook for Electrical Engineers* it is stated concerning the variable speed induction motor:

For any one value of the resistance the speed changes greatly with variations of load and rises practically to synchronous value at no-load, what-

ever the resistance. The higher the resistance, the more the speed will vary for a small change in load. An amount of power proportional to the speed reduction is lost in the resistance, that is, if the speed is decreased to 30 per cent below normal, 30 per cent of the energy taken from the line is lost.

Figure 2 shows the relations between horse-power output, efficiency and speed of a 50-horse-power Westinghouse variable speed induction motor used for driving a DeLaval three-stage centrifugal pump in the Hydraulic Laboratory of the University of Illinois. The results of the test of this motor bear out the statements quoted above.

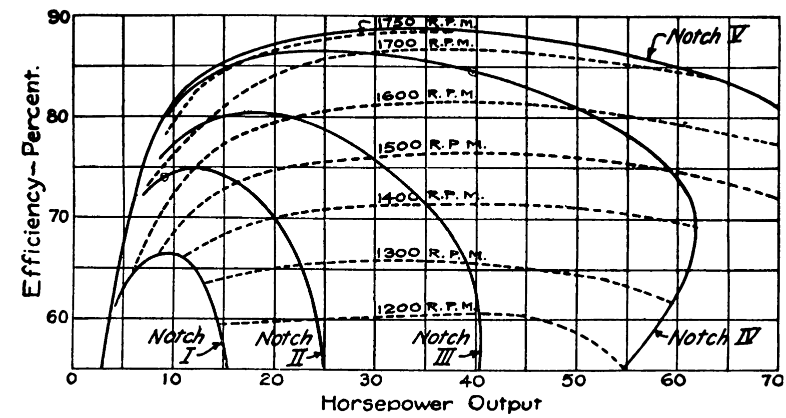

FIG. 2. CURVES SHOWING RELATIONS OF HORSEPOWER OUTPUT, EFFICIENCY AND SPEED OF A WESTINGHOUSE 50-HORSEPOWER, 440-VOLT, 60-CYCLE, 2-PHASE VARIABLE-SPEED INDUCTION MOTOR

When the head developed by the pump is in excess of the head required under the given condition of speed and discharge, the excess head is usually wasted through a partly closed valve. The power input to the pump remains unchanged because the pump continues to deliver the given quantity of water against the same head no matter how much the valve is throttled. The power used in producing the excess head is wasted. If, however, the speed of the pump is reduced to the proper amount it will not be necessary to waste head through a valve. The head developed by a centrifugal pump varies as the square of the speed when the discharge is zero, and varies approximately as the square of the speed for any discharge within the usual range of operation. If the speed is

reduced to 90 per cent of the original speed, the head will be reduced to about 81 per cent of the original head. If this change of speed is accomplished by means of a variable speed induction motor, the efficiency of the motor will be reduced to 90 per cent of the original efficiency. The efficiency of the pump usually does not change materially within such a range of operation. If the head be reduced to 81 per cent of the original head by throttling a valve, the over-all efficiency will be reduced to 81 per cent of the original over-all efficiency. That is, the use of the variable speed motor to decrease the head to 81 per cent of the original value reduces the over-all efficiency by 10 per cent, as compared with a reduction of 19 per cent in case a valve is throttled.

In the case of a motor-driven pump having an over-all efficiency of 55 per cent, delivering 1000 gallons per minute against a maximum head of 100 feet, but operating against a head of 90 feet half of the time, a saving of about $150 a year would be effected by the use of a variable speed induction motor instead of a squirrel cage motor, it being assumed that power costs 2 cents per kilowatt-hour. Approximately the same annual saving would be effected by the use of a variable speed motor with a pump of the above capacity and efficiency for any maximum head provided that the pump operates half of the time at a head 10 feet less than the maximum.

Figure 3 gives the results of tests on a DeLaval three-stage centrifugal pump direct-connected to a Westinghouse variable speed induction motor. The over-all efficiency of the unit when delivering various quantities of water against various heads is shown when the speed of the unit is varied and also when the unit is run at normal speed and the heads are obtained by throttling the discharge valve. It will be noted that the saving in power effected by the use of the variable speed motor is large when considerable reductions of head are required. The motor driving the pump was arranged for only five running speeds. The smooth curves drawn through the points indicate the over-all efficiency if the resistances introduced into the rotor circuit could be made any desired amount. For the unit used in the tests it is necessary to throttle the discharge valve to obtain heads between those given by the five running speeds. The over-all efficiency for different heads is, therefore, as indicated by the dotted lines in the tests with the discharge of 150 gallons per minute.

In the selection of a variable speed motor to drive a centrifugal pump great care should be taken that the several speed changes shall all be within the range required to produce the specified range of head, and the more speeds within this range the better. The electrical manufacturing companies might well turn their attention to developing an external resistance having a large number of steps.

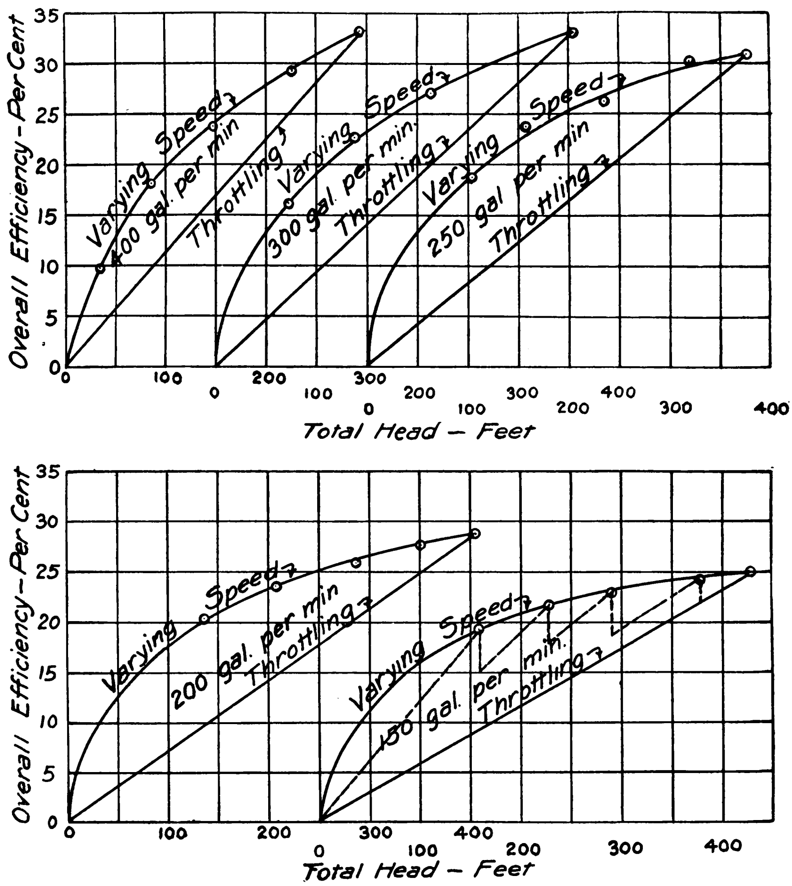

FIG. 3. RESULTS OF TESTS SHOWING OVER-ALL EFFICIENCIES OF A MOTOR-DRIVEN THREE-STAGE CENTRIFUGAL PUMP FOR VARIOUS HEADS AND DISCHARGES WHEN THE SPEED IS VARIED AND WHEN THE PUMP IS RUN AT NORMAL SPEED AND THE DISCHARGE IS THROTTLED

The resistances consist of cast-iron grids compactly arranged, and are connected with the motor through a controller of the type used on street cars. Considerable heat is developed in the grids when the motor is operated at the lower speeds. The grids should, therefore, be located where the heat generated will not be objectionable. Unless the operator is instructed concerning the advantages of the use of variable speed, he is liable to conclude from the heat developed in the grids that it is better to throttle the discharge by means of a valve, because the energy loss in this case is not so apparent although it is in general about twice as great.

The variable speed induction motor is more expensive than the ordinary squirrel cage motor, but the saving in power resulting from its use, when the head varies considerably, will much more than pay the interest and depreciation on the additional investment.